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Measurement of the Dielectric Strength of Quartz Crystalline Material

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The dielectric strength of a sample of a 0.5-mm-thick quartz wafer was measured to be 1.9 MV/cm.

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MEASUREMENT OF THE DIELECTRIC STRENGTH OF QUARTZ CRYSTALLINE MATERIAL

BACKGROUND

High power microwave (HPM) sources require drivers that can generate pulses of very high voltage and very high current. One technique to construct these drivers is to use capacitor banks that are discharged into the radio frequency (RF) generating device. In order to keep these drivers as small and lightweight as possible, capacitors of high-energy storage capability per volume are desirable. The amount of energy a capacitor can store per volume is proportional to the relative dielectric constant and the square of the dielectric strength (DS). But because the DS appears in the square, the DS is the key parameter.

Earlier, we reported[1] the very high dielectric strength of SiO_2 of 9.8 MV/cm. This was measured on samples of thermally grown SiO_2 620 nm thick. For comparison, quartz glass, which is amorphous SiO_2, has a dielectric strength of only 160 kV/cm.

It was not clear whether the exceedingly high dielectric strength of 9.8 MV/cm was due to the very small thickness of the sample, its chemical purity, its crystalline structure, or a combination of all these factors. It is known, however, that the dielectric strength of materials in general increases with decreasing thickness of the sample. Would a quartz crystal considerably thicker than 620 nm still have such great dielectric strength? To find out, we measured the dielectric strength of a 0.5-mm-thick quartz crystal disk. The dielectric strength was found to be 1.9 MV/cm. This report describes the measurement and the results.

MEASUREMENT DESCRIPTION

Several samples of crystalline quartz saw wafers were obtained, courtesy of Hoffman Materials Processing Corp., Carlisle, Pennsylvania. These wafers were 0.02+/-0.002 in. thick and had a diameter of 3 in. They were cut from a solid rod of quartz crystal at 35° 45'.

At first, aluminum electrodes were formed on one wafer by vacuum deposition, on both sides in the center of the wafer. These electrodes which had a diameter of 25 mm were several microns thick.

DC voltage was then connected to the wafer, using a standard DC multiplier as a source. Figure 1 shows the test jig. The voltage was measured by using a calibrated 1-GΩ resistive divider. At about 50 kV, arcing occurred around the wafer on the surface from one electrode to the other, but no damage to the wafer was observed.

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[1] D. Lohrmann, D. Ma, and D. Wu, "On Energy Density in Dielectrics," NRL/MR/5747--98-8197, Naval Research Laboratory, Washington, DC, August 26, 1998.

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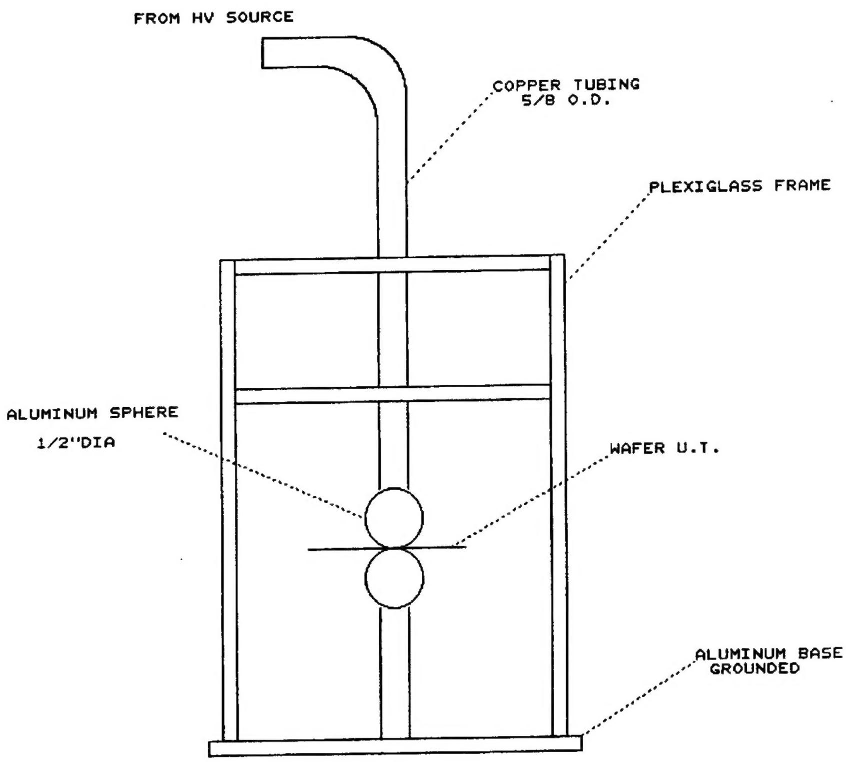

Fig. 1 — Test jig

Next, the assembly (Fig.1) was placed in a plastic bucket filled with transformer oil, type ASTM D-3487-82A Type I. When slowly increasing DC voltage was applied, at about 10 kV, small sparks formed at the edges of the metal film electrodes, which within a few seconds caused heating of the crystal and cracks. Thereafter, only wafers without metallization were used for testing.

Since the output voltage of the DC multiplier was limited to 65 kV, a Van DeGraaff generator capable of generating up to 400 kV was used as a source. Because the Van DeGraaff provided only 7 µA of short circuit current, it was necessary to eliminate current loss by corona effects. Therefore, 17 mm diameter copper pipes were used for conductors outside the transformer oil.

For measuring the voltage, the required 100-GΩ divider resistor was not available. Therefore, a simple contact-free high voltage (HV) voltmeter was constructed as discussed below.

THE CONTACTLESS DC ELECTROSTATIC VOLTMETER AND FIELD INTENSITY METER

Figure 2 shows the contactless electrostatic DC voltmeter. The DC voltage to be measured is connected to a sphere that is suspended by isolators 25 cm above a grounded conducting plane. The sphere is made of aluminum and has a diameter of 10 cm. Underneath the sphere are two conducting plates, mounted insulated 5 mm above the plane. These conducting plates are connected to the input of an FET - OpAmp and through a 1-MΩ resistor to ground. Above the conducting plates is a motor driven grounded vane, which repetitively covers and exposes the conducting plates to the electric field from the sphere. When the plates are exposed, electric field lines end on the plates, producing a charge. When the grounded vane covers the plates, the field on the plates is zero, and hence, the charge disappears. The

result is an AC current flowing from the plates to ground through the 1-MΩ resistor, producing an AC voltage across it, which is amplified by the OpAmp and measured with a standard true rms voltmeter.

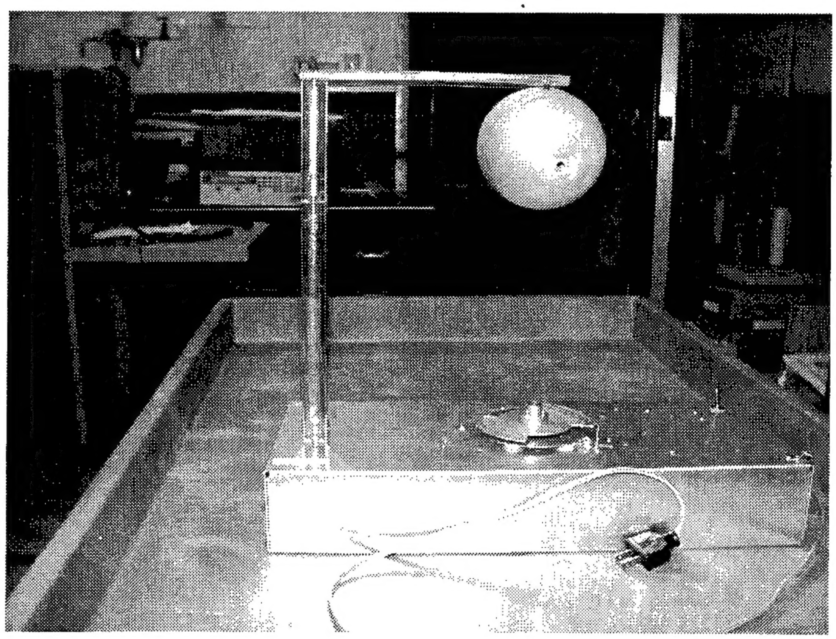

Fig. 2 — Electrostatic voltmeter

Since the vane rotates at approximately 60 rps, the frequency of the output is approximately 120 Hz. The frequency is not exactly 120 Hz due to the slip of the induction motor driving the vane. Figure 3 shows the schematic of the electrostatic voltmeter. It was calibrated by using a standard HV probe and the DC multiplier as a source up to 50 kV. The HV probe was checked using a precision 1 kV source and a digital voltmeter. Figure 4 shows the result of the calibration.

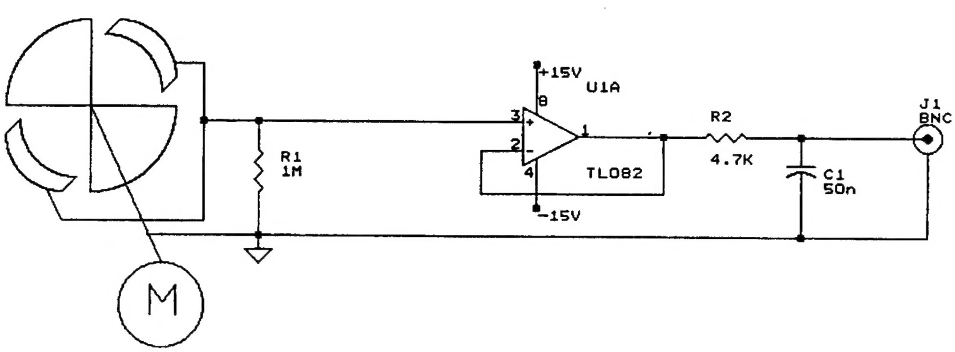

Fig. 3 — Schematic of electrostatic voltmeter

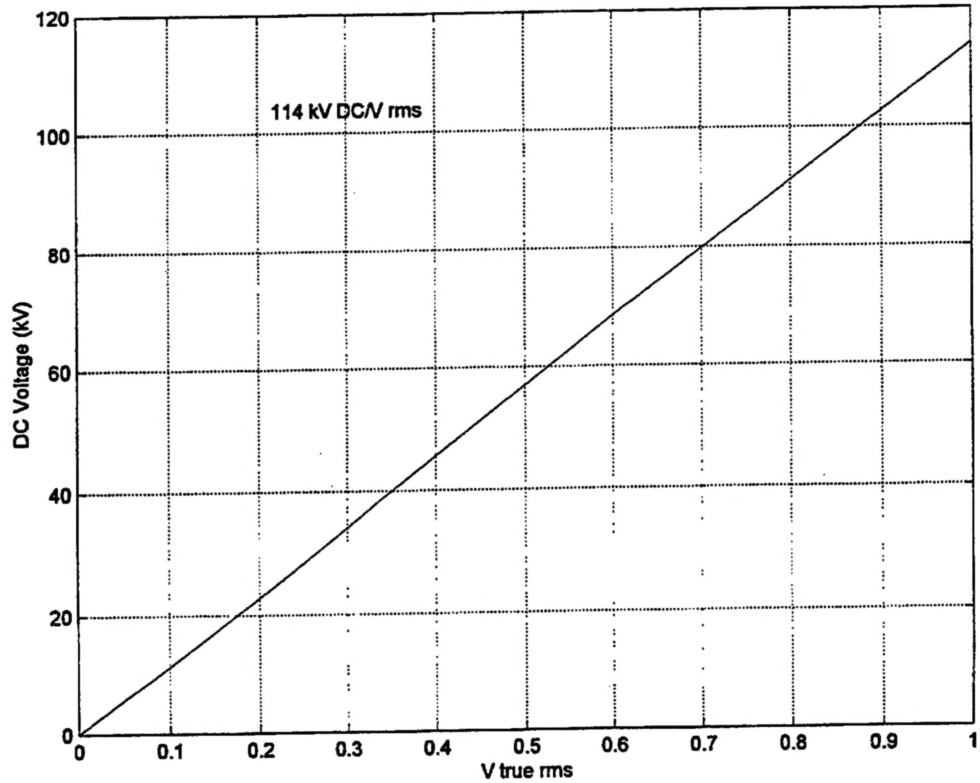

Fig. 4 — Calibration of electrostatic voltmeter

At first, various differing calibration curves were obtained. After the HV source was turned off and the sphere was grounded, and with the motor still running, the AC voltage did not return to zero as expected. The residual AC voltage was up to 20 % of the maximum measured in the actual measurement. The cause was found to be electrostatic charges on the Plexiglas structure supporting the sphere. Moving the Plexiglas rods supporting the sphere away from the vane by 18 cm solved the problem.

This meter can also be used to measure electrical DC field strength.

RESULTS

Wafer # 3 (3 in. diameter, 0.0213" thick, 36° 00') was tested in oil. Figure 5 shows a photograph of the setup.

The spherical probes were placed in the center of the wafer. At 105 kV, the wafer broke through, the discharge punching a tiny hole into the wafer. The DS, therefore, is calculated to be 1.9 MV/cm.

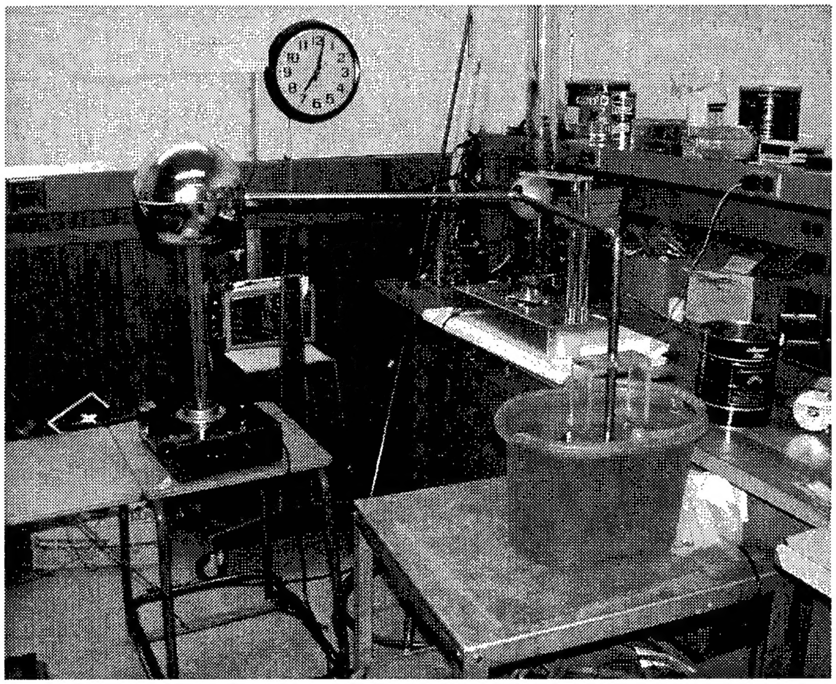

Fig. 5 — Test setup

CONCLUSIONS

The dielectric strength of a 0.5-mm-thick wafer of crystalline silicon dioxide was measured to be 1.9 MV/cm. Amorphous silicon dioxide (quartz glass) has only a DS of 160 kV/cm. Whether the much higher DS of the crystalline material is due to the crystallinity or greater purity is not known at this time. Further, in general, the DS of materials appears to decrease with increasing thickness. However, when the thickness of the crystalline silicon dioxide material was increased from 620 nm to 0.54 mm (a factor of 870), the DS decreased only by a factor of 5. This might suggest that factors other than the thickness, e.g., the purity of the crystalline material, play a role. The 620-nm-thick sample used silicon dioxide of semiconductor type purity; the 0.5-mm-thick sample did not. It appears to be possible that if crystalline silicon dioxide material with semiconductor-type purity could be produced, the DS might be improved beyond the 1.9 MV/cm measured.